Radiation Effects in Glasses for Intrinsic Optical Fibre Radiation Dosimetry

by

Christopher A. G. Kalnins

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Abstract

An optical fibre device has been developed for the purpose of detecting ionising radiation using optically stimulated luminescence. Characterisation of glass materials has been performed, after which optical fibres were fabricated for experiments to demonstrate sensing of ionising radiation.

Fluoride phosphate glass was tested for its capability to sense ionising radiation, primarily using the mechanism of optically stimulated luminescence. The characteristics of the material were determined using a combination of spectroscopy, and thermally and optically stimulated luminescence tests. The sensitivity to ionising radiation was improved by introducing dopant ions into the glass; doping of fluoride phosphate glass with Tb^{3+} was found to increase the intensity of the optically stimulated luminescence response by an order of magnitude, from 7.56×10^6 counts/g/Gy to 100.7×10^6 counts/g/Gy.

Optical fibres were fabricated from fluoride phosphate glass using the extrusion method for fibre preform manufacture. The fabrication process was optimised in each of the extrusion, preform processing and fibre drawing stages to achieve optical fibres with loss of between 0.5 - 1 dB/m for undoped fibres, and between 1 - 4 dB/m for Tb^{3+}-doped fibres. Optical fibres were used for ionising radiation sensing experiments, where the optically stimulated luminescence response was measured following both beta and X-ray irradiation. Following a dose of 14.6 ± 0.5 Gy, optically stimulated luminescence signals were observable using optical fibre lengths of up to 2.6 m, with an integrated OSL intensity of 44.1 ± 13.0 counts.

Silica glass was also tested as an alternative material to perform optical fibre measurements using optically stimulated luminescence. The material was characterised and optical fibres were fabricated with a loss of 0.5 dB/m. Following a dose of 15.5 ± 0.5 Gy, optically stimulated luminescence signals were observable using optical fibre lengths of up to 8.6 m, with an integrated OSL intensity of 385.7 ± 43.4 counts.

Declaration

I, Christopher A. G. Kalnins, declare that this thesis titled 'Radiation Effects in Glasses for Intrinsic Optical Fibre Radiation Dosimetry' and the work presented in it are my own.

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Contents

Summary

This thesis contains a study of the feasibility of detecting ionising radiation with an optical fibre, specifically using the mechanism of optically stimulated luminescence. This work addresses the particular case where the radiation sensing occurs within the optical fibre material, and not in a separate material otherwise spliced to a fibre. The optical fibre therefore acts as both the sensing component of the device, and the waveguiding component which carries a signal to the detector. This work fills a void in the already-established range of optical fibre dosimetry technologies, and provides an alternative method for performing optical fibre dosimetry.

To achieve the project goals, glass materials were studied for their optical, luminescence and radiation detecting properties. These glasses were then fabricated into optical fibres, and these fibres tested in a variety of radiation environments. Work was initially performed with fluoride phosphate glasses, where the glass was characterised and then altered by the addition of various dopant ions to improve its radiation detecting sensitivity. Silica glasses were later studied as a comparison to fluoride phosphate glasses. Also presented is the fabrication of these glass materials into optical fibres of suitable quality to perform distributed sensing measurements of ionising radiation. The performance of the optical fibres are studied under both beta and X-ray irradiation conditions, and their usefulness as dosimeter devices is assessed.

Chapter 1 outlines the context and motivation behind the presented work, and provides a short introduction to the theory behind the experimental work. *Chapter 2* explores the various properties of the materials used for optical fibre fabrication, primarily focusing on fluoride phosphate glasses. In *Chapter 3*, the modification of fluoride phosphate glasses with dopant ions in order to improve the sensitivity as a radiation detecting material is presented. *Chapter 4* presents the fabrication of the radiation sensitive material into optical fibres of sufficient mechanical strength and optical quality for radiation sensing experiments. The radiation sensing experiments for which these optical fibres were used are shown in *Chapter 5*. *Chapter 6* presents an alternative material, silica, and shows how in some areas it can be superior to the materials discussed in previous chapters. *Chapter 7* summarises the experimental work and gives an appraisal on

the feasibility of using this novel method of radiation sensing in real-world applications; this is followed by a summary of future directions for this area of research.

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